NEARSHORE CIRCULATION ON VARIABLE BATHYMETRY

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1. LONG TERM GOAL

The long-term goal of this research is to increase our understanding and capabilities of predictive modeling of short-wave-averaged nearshore circulation patterns (shoreline to nominally 15m depth), through use of a combination of numerical modelling and data analysis from field and laboratory experiments.

2. OBJECTIVES

The project contributes to achieving the long term goal by investigating the effects of longshore variations of the bottom topography and short-wave field on the short-wave-induced circulation patterns in the nearshore using numerical modeling, field observations, and laboratory experiments.

3. APPROACH

The work the last year has focused on three tasks

1) Compare results from the analytical model for weak topographical variations Putrevu *et al.*, 1995, POS in the following) with results from the more accurate numerical model to evaluate the accuracy of the simpler analytical model,

2) Conduct combined numerical model and laboratory experiments to study the wave and wave-induced current motion on a barred beach with rip channels,

3) Analyze existing field data to identify suitable situations for comparison with model predictions and carry out such comparisons.

The numerical model used for the computations is the SHORECIRC, which is a comprehensive quasi-3D model for nearshore circulation.

The laboratory experiments were conducted in the 20 x 20 m directional wave basin at the Center for Applied Coastal Research at the University of Delaware. A concrete slope was installed in the basin and a bar installed the width of the tank, with the exception of two rip channels. In the experiments, wave heights and water particle velocities were measured at numerous points inshore and offshore of the bar and within the rip channels.

4. WORK COMPLETED

An extensive comparison has been carried out between the semi-analytical solution of Putrevu *et al.* (1995) [POS] and the more complete numerical SHORECIRC model.

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The comparison included both the case of a plane beach with sinusoidally varying topography in the longshore direction which was described in the paper, and a case with a longshore bar with a weak rip-channel.

Laboratory experiments have been carried out in the directional wave basin at the Center for Applied Coastal Research using a fixed bottom beach with a longshore bar. At two points the bar is disrupted by rip channels. The major experiment includes 128 records of water surface (and mean water level) variation and 120 recordings of particle velocities, measured by a movable array of 10 wave gages and three acoustic doppler current meters (measuring both horizontal velocities). Tests were also performed to determine basin seiching frequencies, reflection characteristics of the beach and bar, and to determine when the rip current would be present.

Numerical experiments were also conducted with the SHORECIRC model for a number of situations corresponding to conditions that occured during the DELILAH field experiments 1990. The short wave data were derived from the measurements at the 8-m array, while the flow measurement used for the comparisons were all taken by the instruments in the large cross-shore array with 9 measuring positions in the cross-shore direction.

5. RESULTS

For plane beach with small (sinusoidal) longshore topography variations, the approximate POS theory gives very accurate results even though the longshore current is substantially modified by the longshore pressure gradients that develop.

On a barred beach with a weak rip channel, however, the POS theory turns out to give misleading results. The POS theory predicts the development of a strong rip-current, where the full model only gives a small modulation of the largely longshore flow field. Fig 1 illustrates the difference between results from the two models.

A closer analysis of the reason for this difference between the two theories suggest that two small terms left out of the equations in the POS-model are important. Adding just those two terms to the POS model givess a significant improvement of the model accuracy. It is clear from the results that the longshore pressure gradient is a very important forcing mechanism for longshore currents, which was one of the working hypotheses for this project. But other mechanisms are important too.

The laboratory experiments verify that the waves create a mean set-up of water level behind the bar as predicted by Dalrymple (1974). This set-up drives the fluid in the trough shoreward of the sand bar towards the rip channels, where the flow exits seaward, driven by an additional set-up directly shoreward of the rip channel. A new finding is the instability of the rip currents, which have both long and very long period oscillations (Haller, Dalrymple & Svendsen, 1997). These instabilities are apparently not shear instabilities being generated along the beach and advected offshore in the rip current, but instabilites generated within the rip current itself. The longest oscillation is due to the meandering of the rip currents within the wide rip channel, occurring at roughly 450 seconds, far longer than any basin seiching mode. The cause of the
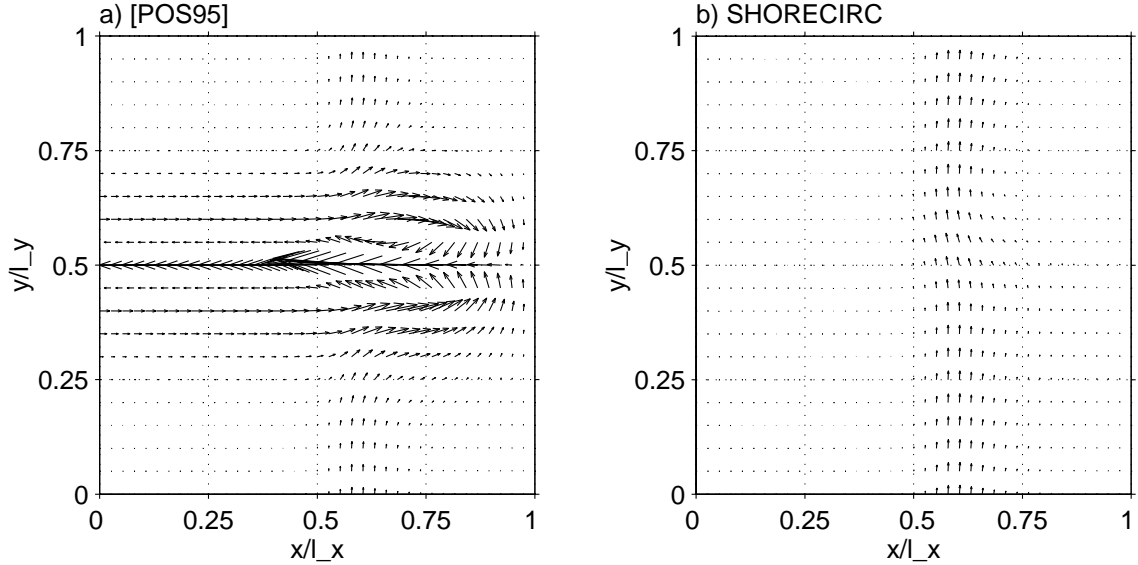
Figure 1: Depth-averaged current vectors over the barred beach with a rip channel of depth 10% of the bar height, and incident wave angle $\alpha_b = 5\,\mathrm{deg}$: (a) Model results from Putrevu at al. (1995); (b) SHORECIRC model results. In the figures the beach is to the right, the short waves forcing the currents come in from the left .

meandering has yet to be determined, although feedback between the strength of the rip current and the incoming waves may be important, as the stronger the current, the further seaward the incoming waves break on the rip current and the stronger the wave-induced refraction/diffraction of the waves in the vicinity of the rip current.

The comparisons with the numerical model are still in their initial phase but show remarkable similarities. Fig 3a & b show an example of the measured and the computed current velocities. Though there are much fewer measured than computed data points there is clear similarity between the measured and the computed flow patterns. There are also temporal oscillations of the currents that can not be seen from the picture.

Several of the flow parameters are very well predicted by the computations including the wave height and the velocities in the cross-shore circulation. In some cases we have difficulties fully reproducing the relatively stong longshore currents velocities measured in the trough, a problem that has also been encountered in the literature with simpler 1D models. We are still searching for answers to this.

6. IMPACT/APPLICATIONS

The numerical computations with a gently varying bathymetry suggest that we have to be very careful when trying to model flows where the longshore variations of particularly the topography play a major role in shaping the currents

While these computations have helped us gain confidence in the model and new
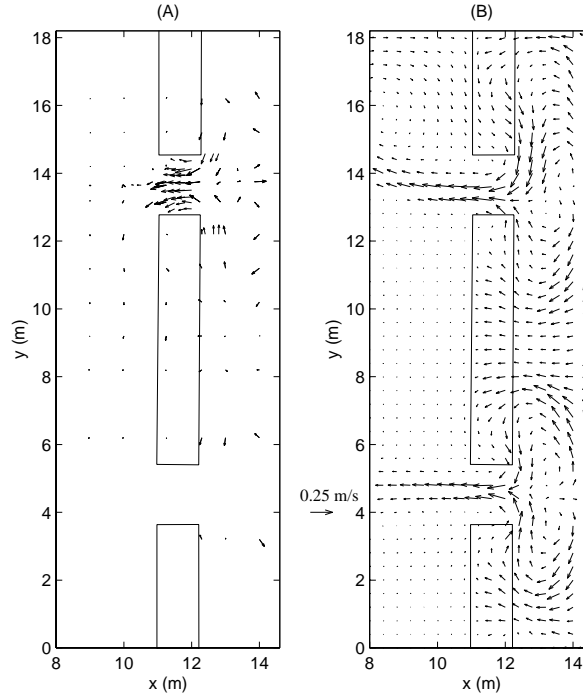
Figure 2: Time averaged current vectors over the barred beach with two rip channels: (a) laboratory measurements, (b) SHORECIRC model results. In the figures the beach is to the right, the short waves forcing the currents come in from the left. The vectors represent the velocities below wave trough level and hence are the velocities recorded by current meters or felt e.g. by underwater swimmers.

insight into several important mechnisms such as the effect of longshore pressure gradients and the causes of rip currents, they have also raised a number of questions such as: when do rip currents through a rip channel occur and when not? And: are rip currents an instability phenomenon that will automatically grow large if occuring at all? To which extent are rip currents surface phenomena with limited depth penetration. We have not yet found the answer to those question but they are well suited to guide future research.

Similarly the laboratory experiments with rip currents are novel. When fully analysed, we expect them to contribute significantly to our understanding of the mechanisms responsible for the creation of rip currents and to form a benchmark data base against which other models can be tested.

Further the unexpected finding of long-term instabilities in the laboratory point out the advantage of physical models in providing unexpected phenomena and providing the impetus to improve the numerical models.

7. TRANSITIONS

There has been significant interest in the SHORECIRC model from several institutions. It has already been transfered to the research group at WES working with the new large scale sediment transport laboratory facility. We are also in contact with NRL at Stennis (Dr. James Kaihatsu) and expect to transfer the model to them soon.

We have had several other less formal requests and expect more when the model and its characteristics become more known. A detailed manual has been developed and is updated regularly as the model is improved. We also expect considerable interest in the laboratory measurements when they become publicly available.

8. RELATED PROJECTS

The following are related projects in which the PI's are involved in conjunction with the Coastal Dynamics program of ONR, the ARO, and the NOAA Sea Grant program:

1) The flow conditions in and near the turbulent front of a hydraulic jump are being analysed. This work is near completion and is expected to generate two journal papers, one on the hydraulic jump analysis, and one describing how those results can be applied to spilling breakers. The work was presented at the Coastal Dynamics '97 conference and created significant interest (PhD project).

2) Together with D.H. Peregrine and his group model improvement is sought for the Boussinesq model for breaking waves. A first version of the model was published in the procedings of the 25th International Coastal Engineering Conference (1996).

3) The mechanisms behind the formation of rip currents and the 3D effects of the vertical variation of the velocities within such currents are being studied (PhD project).

4) Analysis of the generation and propagation of IG waves using the SHORECIRC model. We think we have identified a mechanism that explains why in some cases field data show incident IG wave energy will increase in some cases decrease in the surfzone (PhD project).

5) The project, hydrodynamic models to interprete remote sensing, has provided the opportunity to apply the Boussinesq model FUNWAVE (Wei *et al.* 1995) to the present laboratory experiment, with very good results.

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